

Sustaining economic expansion in Pakistan in an era of energy shortfalls: growth options to 2035¹

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Abstract

Pakistan's recent economic acceleration together with rapid rates of population growth is having a significant impact on the country's energy supply/demand balances. Energy supplies in turn affect the pace and pattern of the country's economic expansion. Drawing on the empirically-based complex links between energy and the economy, several alternative scenarios of growth and energy needs are developed in an attempt to answer several key questions. In particular, what are some of the key interrelationships between sources of energy demand and supply? What are the economic growth consequences of alternative energy availabilities and, in turn, how do these growth patterns affect the subsequent energy supply and demand patterns? What energy strategies are suggested by the interconnection between the country growth requirements and energy needs? Are these significantly modified under rising or falling energy prices? Based on this analysis, several guidelines are drawn for the country's future energy policy.

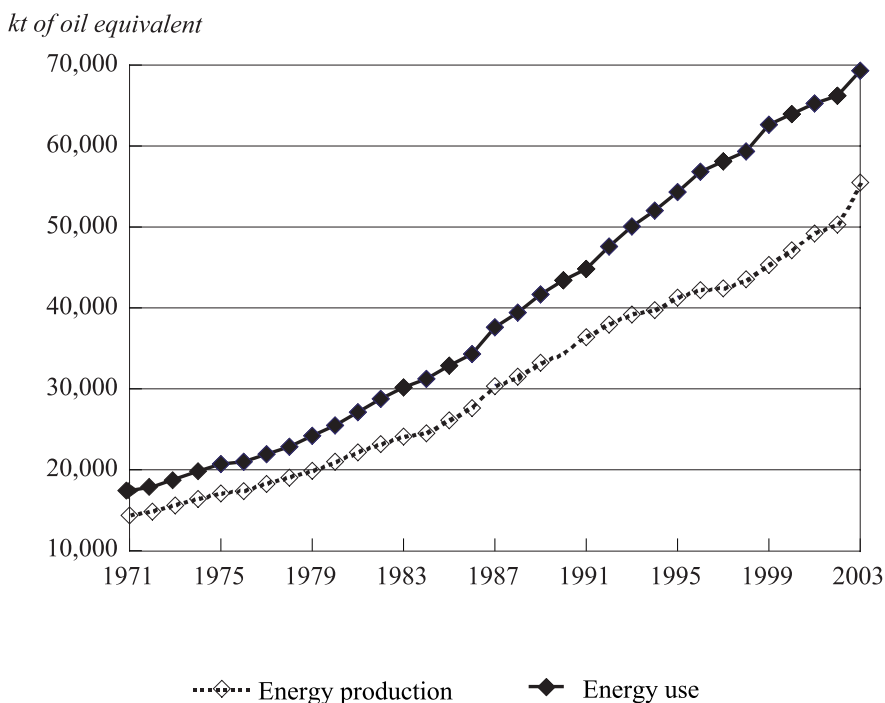
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WITH RAPID ECONOMIC growth in recent years, Pakistan's demand for energy has been increasing at the rate of 10–12 per cent per annum. However, the country's rather static oil, hydroelectric power and gas reserves have raised serious concerns as to the sustainability of the current economic expansion, as well as future economic growth. The gap between Pakistan's energy use and the country's ability to produce energy has widened in an alarming way in recent years (**figure 1**).

As a means of responding to the country's lagging energy supply, the Government has drawn up a 25-year plan (2005–30) for expanding energy production.² Initial cost estimates are staggering – \$37–40 billion, with an average annual investment of approximately \$1.5 bn. Given the country's low rate of domestic savings, much of this expense will have to be met by increased flows of foreign aid, external borrowing, and direct foreign investment – all of which can be somewhat problematic.

Figure 1
Pakistan: energy production consumption gap, 1971–2003



Pakistan's energy plan provides an excellent overview of the challenges facing the country over the next several decades, and it provides a sound, practical, framework for identifying short-term, as well as medium and longer term needs. The

emphasis on developing indigenous sources of energy is sound, especially in light of the country's vast coal deposits and hydroelectric potential. On the other hand, one might question several of the key assumptions upon which the plan is based. The plan assumes high sustained rates of economic growth – above 7.5 per cent will be the norm for the future. This pace of economic expansion in turn defines many of the country's future energy requirements and the proper timing for project implementation.

High sustained growth has not been achieved in the past and, unfortunately, it is unlikely likely to be the dominant pattern for the foreseeable future (Burki, 2006a). Instead, the pattern has been one of roughly a decade of expansion followed by a decade of rather flat growth rates.³ Patterns of this type, if they continue into the future, will create a somewhat different mix of energy requirements than that envisaged in the Energy Plan. Also unclear is the likely pattern of future energy prices – how sensitive are the assumed energy supply demand balances to alternative energy scenarios? Clearly, these will also have a great effect on both the country's supply of and demand for commercial energy.

Taking the cyclical nature of Pakistan's economic performance into account, and drawing on recent empirical research examining the complex links between energy and the economy, the sections that follow attempt to sketch out several alternative scenarios of growth and energy needs. In particular, what are some of the key inter-relationships between sources of energy demand and supply? What are the economic growth consequences of alternative energy availabilities and in turn how do these growth patterns affect the subsequent energy supply and demand patterns? What energy strategies are suggested by the interconnection between the country growth requirements and energy needs? Are these significantly modified under rising or falling energy prices?

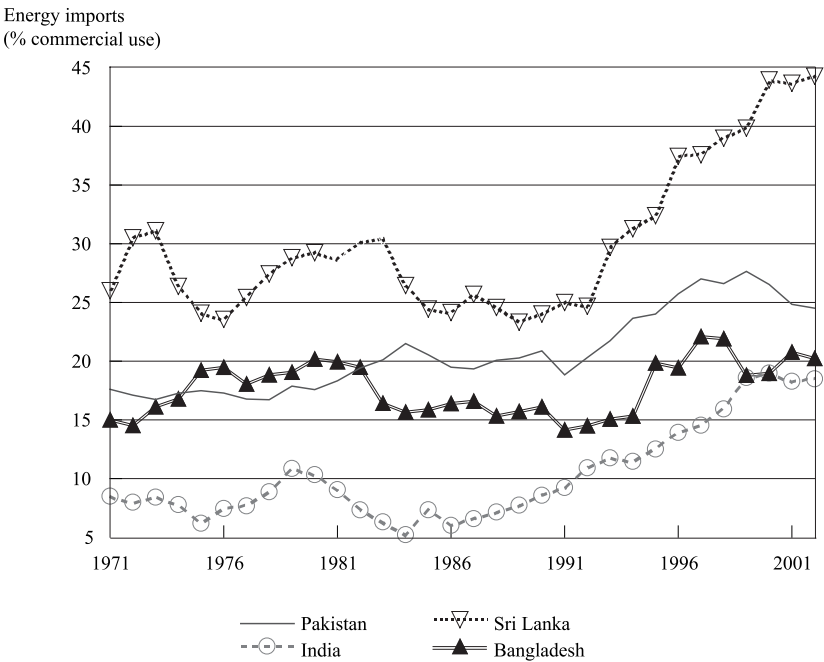
1. Energy and the economy – historical patterns

The cyclical nature of Pakistan's economic progress is sketched out in **table 1**.⁴ The 1960s, 1980s and early 2000s have been periods of rapid expansion in most of the standard macroeconomic growth indices. In turn these have affected, albeit to a lesser extent, the many measures of individual energy supply and demand. Several other patterns are also of particular interest for meeting the country's future energy needs:

1. Capital formation has tended to increase at a slower rate than the overall economy. The International Monetary Fund has suggested (IMF 2005, p. 15) that an increase in investment will be necessary if the current economic expansion is to be sustained. The IMF also notes that the increase in growth over the past several years may have reflected, in part, a reduction in excess capacity, as well as favourable weather conditions that aided agricultural production – two elements that are unlikely to be sustainable in the near term.
2. Domestic oil production has been rather flat in recent years, despite the increase in world oil prices – the country may have great difficulties

in expanding oil production in the future and will need to look to alternative energy sources or become increasingly dependent on expensive oil imports – an alternative likely to greatly limit future economic growth. In this regard, overall energy imports have expanded rapidly in recent years, although not nearly to the extent of other South Asian countries, such as Sri Lanka and India (figure 2).

Figure 2
Energy imports in South Asia



3. The other dominant energy pattern is the long-run shift in power generation from hydro sources to oil and coal generators (figure 3). Clearly, much of the country's current energy crisis stems from the decline in hydro sources of energy and an over-reliance on increasingly expensive sources of electricity. Oil-fired plants presently account for 68 per cent of generation capacity, hydroelectric plants for 30 per cent and nuclear plants for only two per cent. This has led one observer to note that:

This thermal-to-hydro ratio of 68 per cent to 30 per cent is a highly skewed mix from a generation-cost point of view and has had a huge adverse impact on the economy over the last six or seven years as oil prices have risen inexorably, pushing up Pakistan's electricity tariff

Table 1
Pakistan: historical economic and energy trends

	1960s	1970s	1980s	1990s	2000–05
<i>Macroeconomic growth indicators</i>					
GDP	6.79	4.84	6.86	3.98	5.16
Capital formation	9.82	4.49	5.85	1.93	3.81
Infrastructure	10.35	3.27	5.40	3.01	0.42
Manufacturing	9.75	5.60	8.67	4.29	8.19
Agriculture	4.57	2.66	4.43	4.23	2.83
Industry	10.48	6.59	8.19	4.71	7.15
Services	6.80	6.37	6.77	4.53	5.69
Per capita GDP	3.87	1.62	4.02	1.44	2.86
Population	2.80	3.17	2.74	2.50	2.25
Personal consumption per capita	2.28	2.14	1.43	2.36	2.77
Investment per capita	6.82	1.28	3.03	–0.56	1.51
<i>Structural and price patterns</i>					
Share of capital formation in GDP	30.83	21.61	20.62	18.84	15.13
Share of manufacturing in GDP	10.24	11.42	13.00	13.87	15.55
Growth in world oil price (\$/b)		51.52	–2.35	2.04	22.26
Growth in Rupee oil price		66.11	5.52	11.74	26.04
<i>Growth in energy demand</i>					
Oil/petroleum (t)		5.06	8.86	6.37	–1.66
Gas (mm cft)		8.55	7.35	4.92	10.66
Electricity (GWh)		7.86	11.58	4.97	5.99
Coal (metric t)		1.27	7.13	3.30	12.58
<i>Growth in energy supply</i>					
Oil: local crude extraction		4.35	19.35	1.92	3.27
Oil: imports		2.60	0.26	2.23	12.59
Oil: total (b)		2.64	3.88	2.00	9.00

	1960s	1970s	1980s	1990s	2000–05
Petroleum products imports		20.96	12.18	10.20	–8.72
Petroleum products production		2.47	4.39	1.05	10.53
Total petroleum products (<i>t</i>)		5.26	6.99	5.76	–0.40
Gas (<i>mcf</i>)		8.64	7.60	5.08	10.47
Coal production		1.29	7.61	3.64	5.87
Coal imports		–21.48	39.19	0.75	26.59
Total coal (<i>t</i>)		0.90	10.91	2.74	11.09
Electricity installed capacity (<i>MW</i>)		9.73	7.57	8.31	3.70
Electricity generation (<i>GWh</i>)		9.43	9.37	6.61	4.62
Hydroelectric installed capacity (<i>MW</i>)		15.55	6.79	5.81	5.54
Hydroelectric generation (<i>GWh</i>)		13.26	7.69	3.17	3.18
Thermal installed capacity (<i>MW</i>)		8.04	8.98	10.43	2.69
Thermal generation (<i>GWh</i>)		7.44	11.83	9.45	5.05
Nuclear installed capacity (<i>MW</i>)		0.00	0.00	0.00	39.54
Nuclear generation capacity (<i>GWh</i>)		20.81	730.08	89.15	81.94

Sources: Pakistan Economics Survey 2005–06, and various issues, Government of Pakistan of Finance, 2006; International Monetary Fund, International Financial Statistics, various issues; World Bank, World Development Indicators, 2005.

Note: Infrastructure derived from regressing gross fixed capital formation on its lagged value.

to one of the highest in the world. This, in turn, has pushed up manufacturing costs, fuelled inflation, and made Pakistani goods less competitive in export markets, resulting in a growing trade gap and increased pressure on the balance of payments (Omar, 2005).

4. Another important trend is the rapid increase in the share of electricity consumed by households as opposed to industry (**figure 3**). This pattern largely reflects energy pricing and has come under increased criticism by most energy experts (Burki, 2004).
5. Less dramatic are a number of long term relationships that have existed between the economy and energy supply and demand elements, as well as between the various forms of energy consumed and supplied (**table 2**).

Table 2
Pakistan: long-run commercial energy patterns

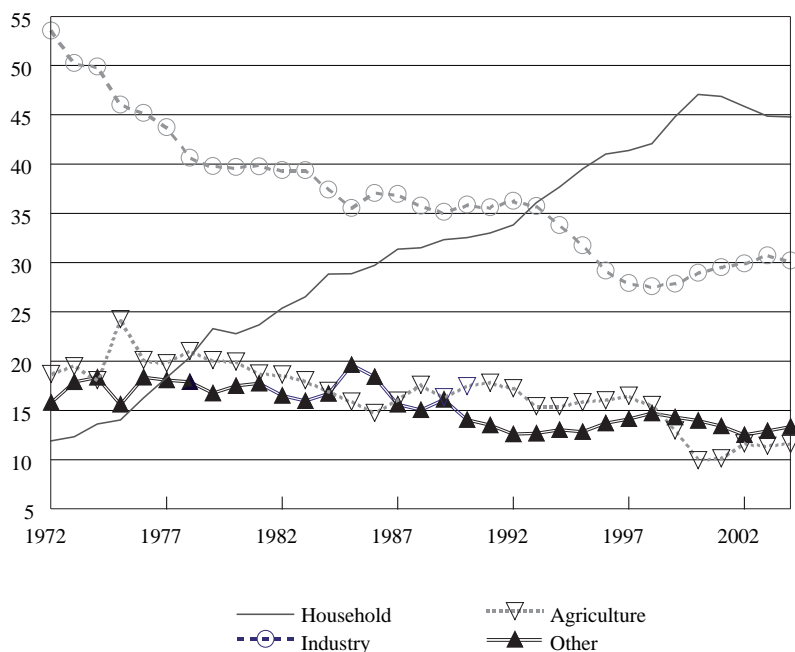
Variable	Per capita GDP significant	Trade-off with alternative energy source	Error-correction statistically significant
<i>Demand interrelationships</i>			
Total oil/petroleum consumption	yes	electricity, negative	yes
	yes	coal, negative	yes
	no	gas, negative	yes
Electricity	yes	gas, positive	yes
	yes	coal, positive	no
Coal	no	gas, positive	no
<i>Supply interrelationships</i>			
Crude oil extraction	no	coal production, positive	yes
	yes	electricity capacity, negative	yes
Gas	yes	total electricity capacity, positive	no
Hydro generation	no	thermal electricity capacity, negative	yes
Thermal generation capacity	no	hydro electricity capacity, negative	yes

Sources: Pakistan Economic Survey 2006–06, and various issues, Government of Pakistan, Ministry of Finance, 2006; International Monetary Fund, International Financial Statistics, various issues; World Bank, World Development Indicators, 2005.

Notes: Estimations made using ARDL approach to cointegration. Estimation interval, 1973–2005, see M. Hashem Pesaran and Bahram Pesaran, working with Microfit 4.0. Interactive Econometric Analysis, Camfit Data, Cambridge England, 1997 for a description of the method used. A statistically significant error-correction term suggests the return to a long-run equilibrium with the equation variables following a sudden movement in one of them. The coefficient of this term is suggestive of the speed of return to equilibrium.

Figure 3
Pakistan: pattern of electricity consumption by user

% of total electricity consumption



Technically,⁵ these long-term relationships are such that any disturbance caused by short-run shocks sets off an adjustment process restoring the longer run patterns. In particular, per capita GDP has a stable relationship with a number of energy consumption patterns including oil/petroleum, electricity, and coal. Within these patterns, a series of positive and negative impacts occur from changes in other forms of energy. For example, increased use of coal and gas, negatively impact on oil/petroleum consumption. In addition, expanded thermal electricity capacity has had a distinct negative effect on hydro generation (and vice versa), leading at least one knowledgeable observer (Burki, 2006) to note that perhaps the government's recent attempt to meet the country's immediate energy needs through thermal generation has significantly delayed the more economically viable alternative of hydroelectric generation capacity.

2. Energy and the economy – empirical studies

Statistical studies of the links between energy and the Pakistani economy have found a number of important relationships. The main finding (Looney, 1992, 1995) is that energy use and economic growth are interrelated in that energy expansion leads to higher growth and, conversely, its shortage may retard the growth process. Also, the different types of energy affect growth in varying ways. In this regard, the impact

of electricity and petroleum products, as well as that of electricity only is high and statistically significant. However, the reverse causality was found critical only in the case of petroleum products.

Focusing on infrastructure and energy, the dominant pattern is one of feedback. Specifically, increases in infrastructure and investment tend to lead to an expansion of energy output. In turn, this expanded output induces further increases in investment and infrastructure. The picture is mixed, however, and generalisations difficult (Looney, 1992) at the subdivision level. For the period 1972–90:

1. As might be anticipated, increases in public infrastructure in the electricity, gas and water sector produced a strong follow on expansion of energy production. On the other hand, public investment in the sector produced only a weak expansion in output.
2. Investment and infrastructure in the Indus Basin – an area where one might expect a number of complementary relationships with energy development – actually experienced a decrease in energy production following expanded investment and infrastructure.
3. General government infrastructure and investment (including that by federal, provincial and local authorities) was only weakly associated with energy production.
4. Federal infrastructure responded fairly strongly to increased levels of energy production. That is, investment by federal authorities did not expand energy output. Instead capital formation by this level of government responded to past increases in energy production.

The general picture that develops is one in which infrastructure development may have lagged somewhat behind the needs created by the economy – this is consistent with the secular decline in infrastructure noted in table 1. It is also apparent that infrastructure and public investment have not initiated an expansion of the energy sector to the extent that the authorities might have hoped. At best, public investment and infrastructure have expanded, but usually only when prompted by increased levels of energy production (and presumably the pressures that have been associated with power shortages, load shedding, etc.)

The above assessment of the interrelationship between public investment and energy development suggests serious output constraints, largely related to insufficient development of domestic resources. This underdevelopment, in turn, is related to low levels of investment which, during 1972–90 had been financed, nearly exclusively by the Federal Government. In fact, energy-sector investments (mostly Water and Power Development Authority) accounted for nearly 50 per cent of the public investment programme in FY 1989 and 45 per cent in FY 1990. The policy implications of these patterns were clear (Looney, 1992, p. 283):

The large percentage of a small public investment programme is both insufficient and unsustainable, because of conflicting demands from other sectors. Therefore, in addition to higher domestic resource mobilisation by the public sector (and by the energy-sector companies), increased private sector investment in energy is essential.

Finally, the links between energy and the economy may be strengthening. Research (Looney, 1995) for the period prior to 1990 cast some doubt on the importance of investment in the energy sector in Pakistan as a means of accelerating economic growth. Specifically, there was little evidence that the overall economic growth of the country had been stimulated by the expansion in energy that took place during the previous decade. Toward the end of the 1980s, the situation appears to have changed. At this time, power outages may have reduced GDP by up to 1.8 per cent (Pasha, 1989). By the early 1990s, this fact, together a positive linkage from energy to private investment, was sufficient to justify accelerating the country's investment in energy capacity. That this acceleration in investment did not occur in the 1990s and into the 2000s (**table 3**) is clearly one of the major contributing factors to the current energy crisis.

Table 3
Pakistan: investment in electricity and gas
(Rupees million, constant prices of 1999–2000)

Year	Total	Private	Public
1999–2000	67,354	15,169	52,185
2000–01	65,582	14,796	50,785
2001–02	52,804	32,632	20,173
2002–03	50,119	23,001	27,118
2003–04	16,934	2,044	14,890
2004–05	25,978	4,926	21,052
2005–06	32,628	11,339	21,290
Average annual growth	<i>–11.40%</i>	<i>–4.70%</i>	<i>–13.90%</i>

Source: Pakistan Economic Survey, 2005–06

3. A macro-energy forecasting model

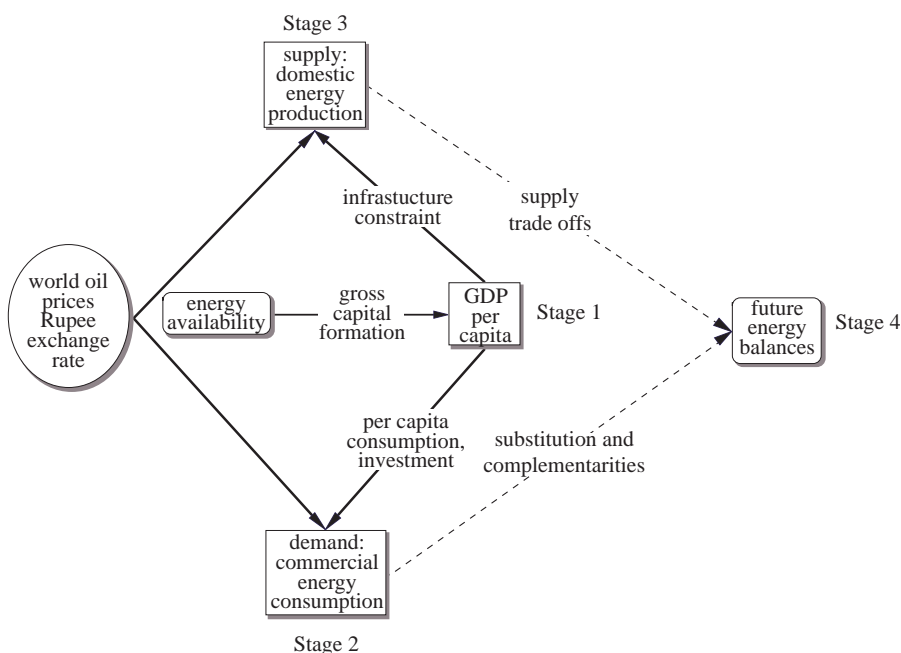
Drawing on the empirical work noted above, a macro-energy forecasting model was constructed. Its main features (**figure 4**) are summarised below:⁶

1. Expanded per capita income is assumed to be a function of energy availability and capital formation. Statistically, in addition to capital

formation, gas, coal and hydro-electric generation have the strongest statistical links to per capita income.

2. In turn, per capita income affects both the demand for total energy, as well as domestic sources of energy.
3. The world dollar price of oil times the Rupee exchange rate was found to be statistically significant in a number of energy supply and demand relationships.
4. As noted above, a number of energy demand relationships are competitive – expanded use of one type of energy comes at the expense of another. Also, several types of energy expansion discourage output increases in others. Complementarities also exist between different types of energy on both the demand and supply side.
5. To capture these effects, a vector autoregression (VAR) model was constructed. The model was then used to quantify past economic/energy patterns as the basis for forecasts to the year 2035. The interre-

Figure 4
Pakistan: macro-energy forecasting model



relationships between the various types of energy are captured through the use of lagged values (previous years). Specifically, each category of energy, for example coal, is estimated based on values of the previous year for other sources of energy – gas, electricity etc in addition to other independent variables such as per capita GDP.

Model Stage I: energy availabilities and future levels of per capita GDP

As a first step in forecasting future energy balances, specified levels of total energy availability – total gas supply, total coal supply and hydroelectric generation (figure 3) together with assumed levels of gross capital formation determine the future values of a number of macroeconomic variables. These include:

- (a) GDP per capita;
- (b) private consumption per capita; and
- (c) government consumption per capita.

Investment per capita and infrastructure were derived from the assumed pattern of investment. The energy variables were selected based on their statistical significance in affecting the macroeconomic variables included in the model. Next, seven different energy/investment scenarios are considered, each based on different assumptions concerning patterns and rates of investment and energy availability. These scenarios are constructed in a manner that assures that overall per capita income increases improve over their historical patterns (table 1). More importantly, energy expansion is not looked at just in terms of specific power outputs. Rather, the models attempt to show the likely manner in which different investment/energy supply mixes interact with the overall economy to produce higher standards of living.

Model 1: Base line forecast – consolidated growth

In this scenario, gross capital formation and the three key energy variables are assumed to expand at a rate of three per cent p.a. This forecast is assumed to be the worst case scenario – the current growth phase ends, resource constraints and perhaps political uncertainties undermine efforts to attract foreign investment and aid. However, investment or energy availability does not decline as dramatically as in the 1970s or 1990s. Growth largely occurs through consolidating and extending various economic and governance reforms.

Model 2: Continuation of the historical pattern of cyclical growth

The current growth phase extends to 2010 followed by flatter growth up to 2020 with another expansion and levelling off in the 2020–30 and 2030–35 periods. The assumed values for the growth of gross capital formation and the energy components for the periods, 2006–10, 2011–20, 2021–30, 2031–35 are as follows: gross capital formation, four per cent, two per cent, four per cent, two per cent; gas, ten per cent, seven per cent, ten per cent, seven per cent; coal, four per cent, 11 per cent, four per cent, 11 per cent; hydro generation, six per cent, four per cent, six per cent, four per cent.

Model 3: Historical pattern of cyclical growth, but with political opposition preventing a major expansion in new dam construction

In this scenario, efforts to overcome regional opposition to new dams fail. As a result, hydroelectric generation expansion is limited to three per cent p.a. Other variables are assumed to expand as in Model 2.

Model 4: Government investment led growth, but with emphasis on social programmes

In this scenario, the country is able to attract and mobilise sufficient resources to sustain rates of gross capital formation at six per cent. However, a shift in expenditure priorities allocates a larger share of government resources to social investments – education, health, etc., rather than energy. The private sector is left to fund added investment in the energy sector. The private sector responds with gas and coal expanding at seven per cent and five per cent, respectively, but hydroelectric generation expanding as the historical pattern assumed in Model 2.

Model 5: Private-sector-led growth

As in Model 4, the private sector mobilises sufficient resources to expand gas and coal supplies by seven per cent and five per cent p.a. over the period to 2035. However, the public sector, unable to pursue adequate tax reform, is constrained to its historical cyclical pattern of investment. As a result gross capital formation and hydro-electric generation are assumed to expand as in Model 2.

Model 6: Expanded dam construction and hydroelectric capacity

Political impediments to new dam construction are overcome; the World Bank and other donors supply adequate funds for a major expansion in the country's hydroelectric generation capacity. Gross capital formation increases at six per cent p.a. with hydroelectric generation expanding as follows: 2006–10, five per cent, 2011–20, seven per cent, 2021–30, nine per cent, 2030–35, 11 per cent. The vast expansion in hydroelectric capacity lessens the perceived profitability of investment in coal and gas development. Total supplies of these energy sources are assumed to expand at rates of three per cent p.a. over the period to 2035.

Model 7: Coal/gas-led energy expansion

For some of the reasons noted above, hydroelectric expansion is constrained and overall investment levels follow the historical cyclical patterns. Concerns over energy shortages, however, lead to the creation of a number of incentives for investment in coal and to a lesser extent gas. Total supplies of these two energy sources are assumed to expand at rates of seven per cent p.a. during the forecasting period.

Each of the models produces a distinctive pattern of per capita income expansion over the period to 2035. All are improvements over the base line forecast. Several results (**table 4**) are of particular interest:

Table 4
Pakistan: growth in per capita GDP under different energy strategies

Average annual growth	2005–09	2010–19	2020–29	2030–35
1. Base line	3.34	2.09	2.34	2.44
2. Historical cyclical pattern	6.11	3.84	6.67	4.90
3. Historical cyclical – lagging hydro	5.53	3.39	6.16	4.56
4. Investment led growth – energy lag	5.03	4.08	5.00	5.09
5. Normal investm./hydro – low coal, gas	4.93	3.66	4.85	4.70
6. High investm./hydro strategy	4.05	3.85	5.56	7.37
7. Moderate emphasis on coal and gas	4.56	3.54	4.54	4.79
8. High emphasis on coal and gas	5.51	5.28	7.27	8.27
9. Maximum growth	6.00	6.55	8.35	9.49

Notes: Simulations based on VAR model of order 2. Dependent variables: (1) per capita GDP, (2) per capita private consumptions, (3) per capita government consumption. Independent variables: (1) gross fixed capital formation, (2) total gas supply, (3) total coal supply and (4) hydroelectric generation. All economic variables are in constant prices of year 2000. Estimation interval, 1973–2000. See M. Hashem Pesaran and Bahram Pesaran, working with Microfit 4.0, Interactive Econometric Analysis Camfit Data, Cambridge, England, 1997, for a description of the method used.

Simulation assumptions:

Model 1: Investment and energy expand at 3% p.a.

Model 2: For periods 2006–10, 2011–20, 2021–30, 2031–35: investment 4%, 2%, 4 %, 2%; gas 10%, 7%, 10%; coal 4%, 11%, 4%, 11%; hydro 7%, 4%, 6%, 4%.

Model 3: Model 2 pattern of investment, coal and gas, but hydroelectric generation held to 3% p.a.

Model 4: Investment 6%, gas 7%, coal 5%, hydro as in Model 2.

Model 5: Gas 7%, coal 5% investment and hydro as in Model 2.

Model 6: Investment 6%, gas 3%, coal 3%, hydro 2006–10: 5%, 2011–20: 7%, 2021–20: 9%, 2030–35: 11%.

Model 7: Investment as in Model 2, gas 7%, coal 11%, hydro 3%.

Model 8: Investment as in Model 2, gas 10%, coal 11%, hydro 3%.

Model 9: Investment 6%, gas 10%, coal 11%, hydro as in Model 6.

Sources: Pakistan Economic Survey 2005–06, and various issues, Government of Pakistan, Ministry of Finance, 2006; International Monetary Fund, International Financial Statistics, various issues, World Bank, World Development Indicators, 2005.

1. As might be expected, maximum growth occurs in later periods under the major expansion in hydro capacity (Model 6).
2. The limited development of domestic coal (Model 5) seems to provide the least satisfactory of the highly viable strategies. Growth rates under this strategy lag considerably behind the historical/cyclical scenario (Model 2).
3. The historical cyclical pattern (Model 2) has the quickest pay-off, but its boom and bust nature may make for lower rates of investment in certain types of domestic energy. Based on the workings of the macro-energy model, lower rates of investment would have their greatest impact on domestic supplies of thermal electricity generation.
4. A strategy emphasising coal and gas (Model 7) produces quicker gains in income than the hydro strategy, but after 2010 the hydro strategy results in more rapid gains in per capita income.
5. High sustained growth can occur without a major expansion in energy (Model 4). However, with changing and unforeseen future technologies, this may be a risky alternative exposing the country to world energy price fluctuations and interruption of supplies.

The results should be taken with a note of caution – they are simply suggestive of certain patterns on the assumption that many historical relationships continue to prevail. Clearly, unforeseen shocks during the forecast period would modify, perhaps significantly, the rates of per capita income growth reported below. Another factor to consider is the actual feasibility of a particular model. Clearly, Model 1 is more feasible than Models 4 or 6, which rely on sustained levels of investment well over those experienced in the past.

Finally, as the models' relationships weaken due to future policy changes such as price deregulation, the relationships will be further modified. Looked at from this perspective, the models' forecast of future consumption patterns balanced against likely expansion of domestic energy sources provides a framework for examining various policy options.

Model Stage 2: Future patterns of energy consumption

Future patterns of energy consumption associated with each of the models summarised above are derived from another VAR model using as key inputs, the output from the first stage of the macro-energy model – primarily GDP per capita and personal consumption per capita. In addition, another variable reflecting broad world oil price movements is introduced. Despite the fact that world oil price movements are not translated directly into the domestic prices for various types of energy, several highly statistically significant relationships were found.⁷ In particular, gas and coal

consumption in Pakistan has increased fairly markedly with increases in the world price of oil. Electricity has been less affected by oil prices, and consumption of oil/petroleum products does not appear to be influenced by world oil prices.

The VAR model was specified so that in addition to per capita GDP, per capita consumption and oil prices, consumption of the main energy components is a function of the past consumption of the other main sources of fuel. This specification facilitates the identification of possible energy demand trade-offs – the substitution of one type of energy by another. Here, several patterns were found to stand out (**table 5**):⁸

Table 5
Pakistan: energy trade-offs and complementarities

Energy consumption	Oil/petroleum	Gas	Electricity	Coal
	gas (–)	oil/petroleum coal (–, strong)	none	oil/petroleum (–, strong)
Domestic production	petroleum products	gas	thermal electricity	coal
	thermal (+) electricity	petroleum products (+, strong)	coal (+, strong)	thermal electricity (–)
	coal (–, strong)			

1. If the goal of Pakistan's energy policy is to reduce dependence on oil and petroleum, then expanded gas consumption is one possible strategy, although this relationship appeared relatively weak in the macro-energy model.
2. On the other hand, both oil/petroleum and particularly coal consumption appear to come at the expense of gas consumption.
3. Other fuels do not appear to compete with electricity, while expanded consumption of oil/petroleum has sharply reduced coal consumption.

Model Stage 3: Future patterns of domestic energy production

As with energy demand, future patterns of domestic energy production associated with Models 1–7 were identified with a third VAR model using the output from the first stage of the macro-energy model. To capture supply side constraints as opposed to the previous demand oriented assessment, infrastructure was substituted for per capita consumption as an independent variable along with per capita GDP and world oil prices. In the case of supply, increased oil prices provided a strong stimulus to increased gas production, as well as thermal electricity. Infrastructure constraints were mainly associated with thermal electricity.

The main energy supply trade-offs identified by the VAR model showed (table 4) petroleum products to be adversely affected by expanded thermal electricity. Somewhat surprisingly, thermal electricity also had a weak adverse effect on coal production – no doubt the result of the substitution of oil for coal in generating electricity. Increased production of coal on the other hand was strongly associated with higher levels of thermal electricity.

Model Stage 4: Future energy demand supply balances

The results of the forecasts of energy demand and domestic supplies produced in stages 3 and 4 yielded some interesting patterns. Two sets of forecasts were made: (1) the first under the assumption of gradually falling oil prices – the world oil price, converted to rupees, declining at an average rate of three per cent p.a. over the forecast period; and (2) the second in an environment of gradually rising oil prices – three per cent p.a.

The results of the first set of supply demand balances are summarised in **table 6**, while the results for the second set are reported in **table 7**.

It should be noted that the supply demand balances by type of energy are not strictly comparable due to the manner in which the first stage model was constructed. The first stage model was primarily interested in examining the effects of energy availability, especially hydro electricity on economic growth. The macro economic variables used in the supply and demand forecasts – per capita GDP, per capita private consumption, and investment per capita – have already factored in hydro's contribution to the country's electricity supply.

The supply forecasts presented in tables 6 and 7 are for the expansion in thermal capacity. No assumptions were made concerning nuclear generation of electricity. Total domestic generation of electricity would, therefore, be the assumed levels of hydro generation plus that generated from the forecasted thermal capacity and whatever nuclear power might be made available in the future. Since hydro electricity currently comprises approximately 30 per cent of total electricity even at fast rates of expansion, it will be some time before this source of electricity makes a significant contribution to the country's overall electricity supply. Hence, the thermal energy forecasts are suggestive, albeit very roughly, of the likely supply situation.

A second factor to keep in mind in interpreting the future energy supply and demand balances presented in table 6 is that the supply of energy does not include domestic oil extraction. Domestic oil extraction was not correlated with any of the variables in the VAR energy supply model. Specifically, production of this energy source does not appear to be greatly affected by per capita GDP, infrastructure or oil prices. Nor is oil extraction influenced by the production levels of other energy variables. In addition there are great uncertainties as to the amount of reserves the country will be able to develop in the future – past rates of extraction no doubt provide little insights as to future rates of production. The prospects are not bright for major discoveries, although some off-shore areas show some promise. In short, there is little basis on which to project this source of energy.

A related issue concerns the breakdown by energy sub-category in the available data. The Pakistan Economic Survey publishes data on the supply of petroleum

products but no separate figure for the demand for this category of energy. Comparisons of demand (oil/petroleum) and supply (petroleum products) provide only the roughest picture for this category of energy. Taking these caveats into account, several distinctive supply/demand patterns emerge:

Model 1: At low rates of economic growth and falling oil prices, gas supplies would run well below demand in the years up to 2030. Electricity supplies would be short of anticipated need between 2010 and 2020 and perhaps again after 2030. Considerable amounts of coal are currently imported, but these would likely decline in the early years. Coal shortfalls might appear after 2010, becoming particularly severe in the 2020s. The gap between the demand for oil/petroleum and the supply of petroleum products would be particularly severe the early years – up to 2010. However, after 2010, supply and demand come more into balance.

With rising oil prices, the situation changes dramatically. Gas supplies are roughly in line with demand throughout the forecast period. Coal supplies improve dramatically in the period up to 2010 and might not encounter shortfalls until the 2020s. Also, a big jump in thermal electricity generation relieves pressures in the electricity markets throughout the forecast period. The oil/petroleum and petroleum products segment of the energy market follows essentially the same patterns experienced with falling oil prices – severe shortfalls in the period up to 2010 followed by a rough balance throughout the rest of the forecast period.

Model 2: A continuation of the country's pattern of cyclical economic growth during a prolonged period of falling oil prices produces a sharply contrasting picture. Domestic gas production lags considerably behind demand throughout the forecast period up to 2030. Electricity supplies might be adequate up to 2010, but would experience a severe shortfall up to 2020, remaining in rough balance for the rest of the forecast period. Coal supplies are also adequate up to 2010, but might experience shortfalls after that date. As with Model 1 the gap between oil/petroleum and petroleum products is severe in the early years, but not after 2010.

With rising oil prices, domestic gas supplies improve dramatically. However, the demand for gas also increases somewhat. The net result is a shortfall throughout the entire forecasting period, with the shortfalls becoming particularly severe in the 2020s in to the early 2030s. Electricity supplies also expand, but not enough to stave off severe shortfalls in the 2020s. In contrast, coal follows a pattern similar to what might be expected in a period of falling prices – initial surpluses, followed by a long period of rough supply demand balance, with perhaps demand slightly outrunning supply. Oil/petroleum and petroleum products fluctuate between severe shortages in the initial years, balance up to 2020 followed by surpluses in the 2020s and deficits in the early 2030s.

Table 6
Pakistan: energy demand supply balance – gradually falling oil prices
(average annual rates of growth)

	Demand for energy					Domestic production			
	2006–09	2010–19	2020–29	2030–35		2006–09	2010–19	2020–29	2030–35
Model 1					Model 1				
Oil/petroleum	7.01	2.73	0.60	0.90	Petroleum products	-2.35	2.89	1.19	2.18
Gas	3.10	1.18	1.34	1.72	Gas	2.48	0.76	0.83	1.73
Electricity	5.46	2.30	1.93	2.18	Thermal electricity	7.16	0.85	2.13	1.82
Coal	2.00	2.23	3.48	3.37	Coal	5.88	2.18	2.65	2.81
Model 2					Model 2				
Oil/petroleum	4.99	2.36	-5.37	4.63	Petroleum products	-0.59	2.93	2.77	2.85
Gas	4.87	2.58	5.06	4.00	Gas	2.99	1.01	2.01	2.57
Electricity	6.62	3.46	4.50	4.20	Thermal electricity	5.92	1.31	1.21	5.30
Coal	6.08	4.97	8.56	5.03	Coal	9.70	4.38	7.68	4.89
Model 3					Model 3				
Oil/petroleum	4.04	2.93	-7.79	7.30	Petroleum products	-1.03	3.06	2.47	3.46
Gas	4.85	1.98	4.77	3.13	Gas	2.92	1.01	1.89	2.60
Electricity	6.48	2.84	3.91	3.09	Thermal electricity	6.31	1.26	1.72	4.68
Coal	5.92	3.95	8.53	4.05	Coal	8.89	3.83	7.19	4.62
Model 4					Model 4				
Oil/petroleum	6.94	5.63	3.52	4.40	Petroleum products	-1.36	4.26	4.11	4.83
Gas	3.95	2.30	3.89	4.38	Gas	2.94	2.42	3.68	4.81
Electricity	6.26	4.08	4.47	5.05	Thermal electricity	6.81	3.90	4.66	5.81
Coal	3.85	3.76	5.89	5.94	Coal	8.18	4.33	5.57	5.32

Table 6 (cont'd)

	Demand for energy					Domestic production			
	2006–09	2010–19	2020–29	2030–35		2006–09	2010–19	2020–29	2030–35
Model 5									
Oil/petroleum	6.49	1.96	-0.43	0.22	Petroleum products	-1.43	3.27	1.97	4.10
Gas	4.01	2.48	3.44	4.08	Gas	2.84	1.06	1.72	2.92
Electricity	6.17	3.36	3.61	4.12	Thermal electricity	6.70	0.90	3.02	2.49
Coal	3.99	4.97	6.24	5.63	Coal	8.04	4.22	5.56	5.00
Model 6									
Oil/petroleum	8.19	4.94	2.57	0.51	Petroleum products	-2.03	4.58	4.17	5.95
Gas	3.20	2.28	4.49	7.05	Gas	2.81	2.47	3.68	5.17
Electricity	5.85	4.10	5.37	7.00	Thermal electricity	7.45	3.59	4.57	4.50
Coal	2.02	3.80	7.80	10.13	Coal	6.76	4.09	6.31	8.31
Model 7									
Oil/petroleum	5.24	2.19	-2.61	-2.18	Petroleum products	-1.67	3.42	1.75	4.62
Gas	4.17	2.14	3.34	3.85	Gas	2.80	1.08	1.64	3.09
Electricity	6.13	2.93	3.14	3.49	Thermal electricity	6.90	0.77	3.38	1.72
Coal	4.29	4.46	6.28	5.60	Coal	7.58	4.09	5.18	5.36

Table 7
Pakistan: energy demand supply balance – gradually increasing oil prices
(average annual rates of growth)

	Demand for energy					Domestic production			
	2006–09	2010–19	2020–29	2030–35		2006–09	2010–19	2020–29	2030–35
Model 1					Model 1				
Oil/petroleum	8.84	4.56	2.78	2.73	Petroleum products	-2.61	4.78	2.20	2.97
Gas	4.75	3.42	3.06	2.97	Gas	4.84	3.68	2.91	3.12
Electricity	6.31	3.84	3.19	3.06	Thermal electricity	10.46	3.68	3.51	2.93
Coal	2.10	2.23	3.26	3.22	Coal	5.93	2.26	2.85	22.90
Model 2					Model 2				
Oil/petroleum	6.83	4.46	-0.24	5.14	Petroleum products	-0.84	4.69	3.41	3.37
Gas	6.36	4.43	5.54	4.25	Gas	5.32	3.81	3.55	3.46
Electricity	7.39	4.78	5.10	4.43	Thermal electricity	9.33	4.10	2.97	4.91
Coal	6.25	4.92	8.44	4.97	Coal	9.75	4.44	7.74	4.90
Model 3					Model 3				
Oil/petroleum	5.93	4.97	-1.38	6.14	Petroleum products	-1.28	4.84	3.16	3.85
Gas	6.33	3.95	5.35	3.63	Gas	5.25	3.82	3.48	3.49
Electricity	7.25	4.25	4.66	3.60	Thermal electricity	9.68	4.04	3.25	4.56
Coal	6.09	3.89	8.40	3.98	Coal	8.93	3.88	7.26	4.63
Model 4					Model 4				
Oil/petroleum	8.69	6.99	4.55	4.70	Petroleum products	-1.63	5.91	4.46	4.91
Gas	5.47	4.26	4.70	4.56	Gas	5.27	4.84	4.51	4.78
Electricity	7.03	5.33	5.05	5.11	Thermal electricity	10.16	5.89	5.00	5.40
Coal	4.04	3.70	5.71	5.87	Coal	8.23	4.39	5.66	5.32

Table 7 (*cont'd*)

	Demand for energy					Domestic production			
	2006-09	2010-19	2020-29	2030-35		2006-09	2010-19	2020-29	2030-35
Model 5					Model 1				
Oil/petroleum	8.26	4.05	2.37	2.67	Petroleum products	-1.69	5.05	2.76	4.36
Gas	5.53	4.40	4.36	4.35	Gas	5.18	3.86	3.38	3.68
Electricity	6.94	4.71	4.39	4.40	Thermal electricity	10.04	3.76	4.05	3.26
Coal	4.18	4.91	6.09	5.57	Coal	8.09	4.28	5.65	5.01
Model 6					Model 2				
Oil/petroleum	9.88	6.36	3.86	2.03	Petroleum products	-2.30	6.24	4.51	5.85
Gas	4.76	4.29	5.16	6.51	Gas	5.15	4.89	4.51	5.02
Electricity	6.63	5.37	5.80	6.73	Thermal electricity	10.75	5.62	4.94	4.47
Coal	2.22	3.74	7.64	10.13	Coal	6.82	4.15	6.40	8.27
Model 7					Model 3				
Oil/petroleum	8.55	4.24	2.90	2.04	Petroleum products	-1.93	5.19	2.58	4.77
Gas	5.32	4.30	4.06	4.52	Gas	5.14	3.88	3.33	3.78
Electricity	6.86	4.42	4.03	4.08	Thermal electricity	10.23	3.65	4.28	2.79
Coal	3.70	4.36	5.49	5.75	Coal	7.63	4.15	5.29	5.37

Model 3: In an era of falling energy prices and with hydroelectricity held at low levels of expansion, electricity experiences shortfalls up to 2030, with the gap between demand and supply especially severe in the 2020s. Domestic gas supplies are also inadequate throughout the forecast period. The pattern is one of moderate shortfalls up to 2010 gradually worsening up to 2030. In contrast, coal might not experience a shortfall with regard to demand until the 2020s with supply outrunning demand again in the early 2030s. Oil/petroleum and petroleum products are again in deficit in the early years, roughly in balance up to 2020 with large surpluses in the 2020s. Deficits, however, return in the early 2030s.

With rising oil prices, thermal electricity expands sufficiently to meet domestic demand. However, a shortfall is likely in the 2030s with demand again surpassing supply. Coal production expands faster than demand in the early years significantly reducing imports. After 2010, supply and demand are in rough balance. Although gas production again increases with rising oil prices, production increases lag behind expanded demand throughout the period up to 2035. The gap between demand and supply becomes particularly large in the 2020s. Oil/petroleum and petroleum products continue their fluctuating pattern of alternating deficits and surpluses beginning with large deficits in the period up to 2010.

Model 4: High rates of overall national investment produce another unique pattern of energy balances. With falling oil prices, the gaps between demand and supply are generally lower than in the two previous models. After an initial period of early shortfalls, gas production expands to meet demand over the remainder of the forecast period. In addition, over the whole forecast period electricity supplies also expand at a slightly faster rate than demand. The same is true for coal, with the exception of a slight supply shortfall in the early 2030s. Even the fluctuations in oil/petroleum petroleum products are dampened, especially after an initial period of sharp shortfalls.

Rising oil prices do not fundamentally alter this picture. Instead in most cases supply improves slightly relative to demand to further relieve pressures in the energy markets.

Model 5 is characterised by a limited availability of coal, together with a cyclical pattern of investment similar to that experienced in the past. If oil prices experience a gradual decline, energy supply and demand balances are not particularly favourable. A sizeable gas shortfall occurs in the early years to 2010, increasing somewhat in the years to 2020 and then continuing to 2035. After an initial period of coal production expanding faster than demand, it also experiences shortfalls to the end of the projection period. These may not, however, be as significant as those associated with gas. After an initial surplus, terminal electricity expansion lags behind expected need, although this may be largely made up with the anticipated expansion from hydro sources. After an initial deficit, only oil/petroleum petroleum products experience sustained periods of domestic supply exceeding demand.

While Model 5 produces a very favourable set of energy balances for falling oil prices, the shifts in demand toward gas, coal and electricity with rising oil prices

erode much of this potential gain. Gas demand consistently outruns supply as is also the case for coal after 2010. Electricity follows the same path as coal, but again expanded hydroelectric sources assumed in stage 1 of the macro energy model, six per cent for 2006–10, four per cent for 2011–20, six per cent for 2021–30, and four per cent for 2030–35 may be sufficient to accommodate expanded demand. The Oil/petroleum and petroleum products balance is also not as favourable as in the case of falling oil prices. Still, after an initial deficit experienced in other models, supply matches demand fairly closely until 2030 when it accelerates more rapidly.

Model 6 focuses on expanded hydro sources of electricity together with high overall rates of sustained investment. As noted in the discussion of the macro energy model, this combination results in a sustained acceleration of per capita GDP after 2010. The resulting increase in demand for other energy resources together with a stimulus to expand other sources of energy produces a unique pattern of energy balances. After an initial shortfall of supply, the oil/petroleum – petroleum products balance is nearly equalised in the period up to 2020. Gas on the other hand, experiences chronic shortfalls of supply especially in the 2020s. Supplies of electricity should be adequate, especially in light of the acceleration in hydro sources. Still, thermal capacity is projected to lag somewhat behind overall electricity demand after 2010. Domestic coal expansion also fails to meet the expanded demand after 2010.

As in the earlier models, rising oil prices assist in bringing demand and supply increases more into balance. This is especially the case for gas and coal in the period up to 2020, although after that date demand significantly outruns supply.

Model 7 assumes fairly abundant supplies of gas and coal, with investment less dynamic than in the previous model. This produces, except for the base line model, average rates of economic growth somewhat below most of the other models. As noted earlier, it produces higher rates of growth than the hydro strategy in the earlier years, but this growth flattens out in the latter years, falling considerably below that associated with a major expansion in dam construction. With falling world oil prices, this mix produces growth in domestic gas supplies lagging behind demand, especially in the 2020s. After expanding fairly rapidly in the early years, the expansion in domestic coal production also fails to keep pace with demand after 2010. In contrast, thermal electricity keeps up with demand in the early years only to fall sharply behind over the period 2010–20. After that, demand and supply are fairly balanced until shortfalls occur again after 2030. Oil/petroleum – petroleum products revert to its normal pattern of supply lagging behind demand in alternating decades.

Rising oil prices bring coal supply and demand growth largely into equality after 2010. The same is not true of gas, however, where shortfalls continue after 2010. Electricity also fails to keep pace with demand after 2010.

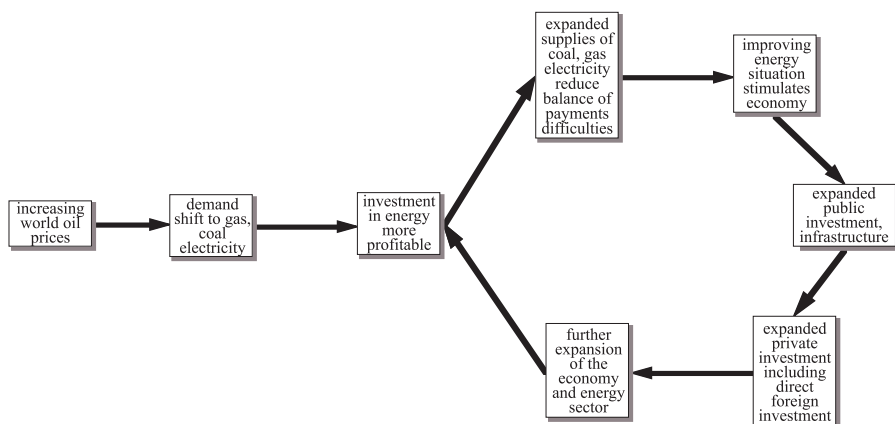
4. Implications

In summing up, which alternatives appear to be the best? While the government has limited control over the manner in which Pakistan's energy picture will unfold,

several generalisations from the models examined above may provide some guidance.

If the goal is to improve energy balances, especially for coal, electricity, and gas, then high oil prices that encourage increased production are more conducive than declining prices. With the good chance of growth accelerating in Models 4, 6, and 7 after 2010, there is a possibility for the establishment of a virtuous circle (**figure 5**) where expanded demand for coal, electricity, and gas increase profitability in these sectors, thus stimulating expanded investment and further growth.

Figure 5
Pakistan: a virtuous circle of expanded energy supply and growth



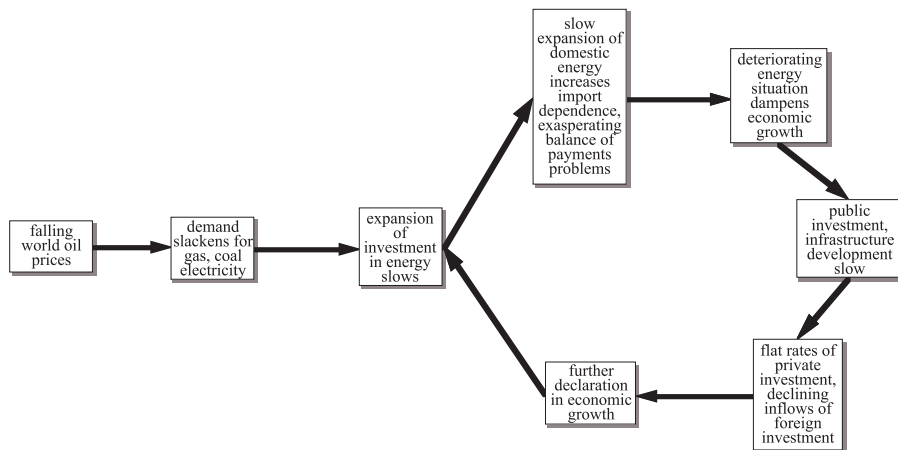
While the government has little control over international prices, it does control the Rupee exchange rate. In this regard, it should not postpone devaluations, but allow the currency to transmit world oil price increases into the domestic market. In the future, the authorities should strive toward an energy pricing system that more reflects the true cost of energy. If high sustained growth is sought, then an environment characterised by high rates of sustained investment together with hydro development (Model 6) may be the best course, especially if substantial loans from international agencies are forthcoming. This environment may be the most conducive to a virtuous circle.

Higher rates of GDP growth have other benefits. Ironically lower rates of economic growth may be more plagued by energy imbalances than higher rates of growth. In the future, low rates of growth may compound this problem by making the country less competitive in attracting significant inflows of direct foreign investment.

If world oil prices fall for a prolonged period of time, the country should definitely pursue a high investment/growth policy such as outlined in Model 4, 6 or 7. With falling profitability in oil, gas, and coal development and the limited prospects for expansion in oil, private investment might not be sufficient to maintain high rates of sustained economic growth. The energy imbalances experienced at low rates of

economic expansion would put stress on the country's balance of payments, further discouraging capital inflows to the country. In short, the high energy imbalances associated with low growth in an atmosphere of falling energy prices is conducive to the creation of a vicious circle (figure 6).

Figure 6
Pakistan: a vicious circle of stunted energy supply and growth



5. Assessment

The purpose of this paper is to provide an exploratory analysis of Pakistan's energy futures. As such, the forecasting model developed here provides only a rough order of magnitudes, and should be looked at as a very preliminary approximation of Pakistan's energy needs. Its strength is in identifying areas of potential trouble and in the need for corrective policy responses. Contrary to the country's energy plans, it has the advantage of taking into account many of the complementarities and competitive relationships between the major types of energy. Its links to the economy also enable energy to be looked at as more than just an output or an end in-and-of itself. In the perspective developed here, energy, while not necessarily a leading sector, takes on the important role of facilitating higher rates of economic growth and material well being. It becomes an integral part of the economy, calling attention to its critical role in the country's future.

While these are valuable aspects, the model clearly has many areas that could be strengthened. The model implicitly assumes that a major goal of energy policy is to become less dependent on imported petroleum and petroleum products. Other objectives should be examined and their feasibility assessed. The same also applies to oil prices – the effects of long run-fluctuations in oil prices rather than steady increases or declines should be explored and their results checked for any marked differences from the results reported above.

Another of refinement called for is a more detailed assessment of the technological, financial and political constraints surrounding the supplies of the various types of energy. For example, have the historical constraints, mainly absence of water in the desert producing locations and limiting the development of coal been overcome through recent technological advances? Are political obstacles to expanded major dam construction likely to constrain the rates of hydro power assumed here? What are the chances of instability in Baluchistan in preventing the expansion of domestic gas supplies projected by the model?

Clearly an important issue not dealt with directly involves regional energy cooperation. Currently Pakistan, along with the other South Asian economies, is exploring the possibility of developing a common energy grid. To date, political obstacles have left some countries with a power deficit and others with abundance. Nepal and Bhutan have substantial untapped hydroelectricity potential, while Bangladesh has large gas reserves that could be used domestically or exported to Pakistan, as well as India and Sri Lanka – if only the infrastructure existed to carry it. While the economic benefits of closer regional cooperation appear clear, competing political interests and, at times, open hostility have stymied the effort.

In terms of imports, the great uncertainty is finance – will Pakistan have the financial resources, or be able to induce international investors to provide some of the magnitudes currently under discussion? In this regard, the Pakistani government is attempting to mobilise international investors to invest in the \$7bn Iran-Pakistan-India pipeline, \$5bn in the Turkmenistan-Pakistan-India pipeline and \$8bn on the Qatar-Pakistan-India gas pipelines.

On a more technical level, while the forecasts suggest that higher oil prices assist in bringing the country's energy supply and demand patterns more in balance, are there any adverse feedback effects on the overall rate of per capita GDP growth? Because no direct statistical links between oil prices and per capita GDP were found, the model implicitly assumes this not to be the case. Yet, common sense suggests that at some point, higher world prices, or perhaps an acceleration in prices, must take a toll on incomes. These possibilities should be examined in greater detail.

While the model suggests certain policy actions, the impact of these measures is difficult to predict in any systematic way. In particular, without a more extensive macroeconomic framework, it is difficult to assess the feasibility of sustained levels of energy imports to bridge the gap between demand and domestic supply. Under certain balance of payment situations, these shortfalls could be easily financed, while under others the same shortfalls would create a severe stress on the economy. Much depends on the availability of foreign direct investment and the extent to which these funds could be directed toward expanding domestic energy sources.

This final point leads to the general conclusion that what takes place outside the energy sector may have consequences that are just as important for the country's energy picture as policies and events directly affecting the sector.

Footnotes

1. *Revised version of paper presented at the Woodrow Wilson International Centre Conference, "Meeting Pakistan's energy needs in the 21st century," Washington, DC, 23 June 2006.*
2. *Useful summaries can be found in Rizvi (2006), Government of Pakistan (2005) and Ali (2005).*
3. *As documented in Looney (2004, 2001).*
4. *Oil prices are from the International Monetary Fund, International Financial Statistics. They are the average crude price in \$/barrel with the average including Dubai Fateh, United Kingdom Brent and West Texas Intermediate.*
5. *They are identified as statistically co-integrated. Cf Pesaran and Pesaran (1997) for a description of this statistical property and the best means to identify its occurrence. See the Appendix for a more detailed description of the approach. Detailed results are available from the author upon request.*
6. *The detailed statistical results are available from the author upon request.*
7. *As noted earlier the oil price proxy is the average world oil price (IMF data) multiplied by the Rupee dollar exchange rate.*
8. *The vector autoregression results are short run impacts – in this case last year's energy consumption of various types on each of the main areas of consumption. As such, the trade-offs are not comparable with the longer term patterns noted in table 2.*

Appendix

Estimation methods

The various statistical relationships noted in table 2 linking energy with the economy were estimated using a cointegration error-correction model (ECM) as developed in Pesaran and Pesaran, Microfit 4.0. The advantage of this model is that it allows the identification of non-spurious relationships without forcing the loss of long-run information. Moreover, ECM allows for suitable economic interpretations since it incorporates equilibrium relationships as suggested by economic theory, along with the possibility of variables responding to short-run disequilibrium. The concept of cointegration provides the link between integrated processes and the concept of equilibrium. It was originally developed by Granger (1980) and extended by Engle and Granger (1987).

More formally, if X_t and Y_t are both non-stationary in levels, but stationary in the first differences, they are said to be integrated of order one, denoted by $I(1)$. If X_t and Y_t are both $I(1)$, their linear combinations of the form $Z_t = X_t - \forall Y_t$ are generally also $I(1)$. However, if there is an \forall such that Z_t is integrated of order zero or $I(0)$, the linear combination of X_t and Y_t is stationary, and the two variables are said to be cointegrated.

Engle and Granger (1987) propose several ways of testing for cointegration. In this paper we use the augmented Dickey-Fuller (ADF) (1981) test, because it has good power properties for first-order and higher-order systems. The ADF test of cointegration consists of first performing the following cointegration regression:

$$X_t = c_0 + c_1 Y_t + \gamma_t \quad (1)$$

Then performing the following ADF regression on the residuals of equation 1

$$\gamma_t - \gamma_{t-1} = b_1 \gamma_{t-1} + \sum_{i=1}^m (\gamma_{t-i} - \gamma_{t-i-1}) + \mu_t \quad (2)$$

The null hypothesis of no cointegration is $H_0 : b_1 = 0$. If the null is rejected, X_t and Y_t are cointegrated.

The cointegration relation $X_t - \forall Y_t = 0$ represents a long-term equilibrium relation between X_t and Y_t , and the cointegration factor Z_t can be used to measure the deviation from this long-term relation. Engle and Granger (1987) suggest estimating the value of \forall by performing the following regression:

$$X_t = \forall_0 + \forall_1 Y_t + \gamma_t \quad (3)$$

By knowing \forall_1 , the cointegration factor Z_t can be obtained from

$$Z_t = X_t - \vartheta Y_t \quad (4)$$

Engle and Granger (1987) combine the concept of causality in the Granger sense and the notion of cointegration to develop a model that allows testing for both short-term and long-term relations between two time series. The model is the ECM. The following ECM investigates the potential long- and short-term effects of X on Y:

$$Y_t - Y_{t-1} = a_0 + a_1 Z_{t-1} + \sum_{i=1}^m b_i \left(X_{t-1} - X_{t-i-1} \right) \sum_{j=1}^m c_j (Y_{t-j} - Y_{t-j-1}) + \gamma_t \quad (5)$$

The ECM of the above equation decomposes the dynamic adjustments of the dependent variable Y into two components. The first is a long-term component given by the cointegration term

$$a_1 Z_{t-1} \quad (6)$$

also known as the error correction term. The correction adjustments of Y_t to a disequilibrium error from the previous period Z_{t-1} can be spread over several periods, with the coefficient a_1 indicating the speed of the correction mechanism. The second component is a short-term component given by the summation terms on the right-hand side of equation 5. These two terms represent past changes in X and Y and characterise the short-term dynamics. Specifically, the first summation term in equation 5 gives the short-term effect of X on Y.

Similarly, the following ECM expresses the long- and short-term effects of Y on X:

$$X_t - X_{t-1} = \vartheta_0 + \vartheta_1 Z_{t-1} + \sum_{i=1}^m N_i \left(Y_{t-i} - Y_{t-i-1} \right) \sum_{j=1}^m \Sigma_j (X_{t-j} - X_{t-j-1}) + \mu_t \quad (7)$$

From equations 5 and 6, it follows that X_t and Y_t are cointegrated when at least one of the coefficients a_1 or ϑ_1 is different from zero. In this case, X_t and Y_t exhibit long-term co-movements. When a_1 is different from zero, but ϑ_1 is zero, Y_t follows and adjusts to X_t in the long term. The opposite occurs when ϑ_1 is different from zero, but a_1 is zero. When both coefficients, a_1 and ϑ_1 are different from zero, a feedback exists and the two variables adjust to one another over the long term.

The coefficients b_i 's and N_i 's represent the short-term relation between X_t and Y_t . When b_i 's are not all zero, but all N_i 's are zero, X is leading or causing Y in the

short term. The reverse is true when N_i 's are not all zero but all b_i 's are zero. When both events occur, a feedback exists and the two variables affect each other in the short term.

A key issue in error-correction cointegration analysis is the specification of an optimal lag structure for the autoregressive model (ARDL) (the author is indebted to an anonymous referee for suggesting this approach). Here we have used the ARDL procedure developed by Pesaran and Pesaran (1997). Essentially, the procedure begins with the selection of a fairly long lag period. The Schwartz-Bayesian criterion is then used to determine the optimal lag pattern. The programme then provides estimates of the ECM which corresponds to the selected ARDL model.

Finally these relationships form the basis of the forecasts developed in Models 1–7. Here, a standard, VAR is developed using lagged values and exogenous specified variables i.e., investment gas, coal, and hydro in Model 1 to forecast future values of per capita income. Again the optimal lag structure of past values is tested using the Schwartz-Bayesian criterion.

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